DESIGN AND QUALITY CONTROL TO INCREASE DURABILITY IN INCHEON BRIDGE PROJECT

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Abstract

The Incheon Bridge is a marine bridge connecting Songdo New Town of Incheon City with Youngjong Island. The whole section of the bridge is constructed by using concrete materials, except the cable-stayed bridge section where it is constructed by steel box girders and stay-cables. Durability Design is applied to toughen the concrete structure of the bridge against Chloride Attack, and the target life cycle is achieved by tightening the concrete and securing the necessary thickness of the reinforcing steel concrete cover in order to ensure the sufficient durability. In case that the mix design of the project is used and the required thickness of the concrete cover is secured, there will be no particular problems in achieving the target life cycle (100 years). Furthermore, continuous quality control is being carried out during the construction work period.

1. PROJECT OVERVIEW

1.1 Introduction

Incheon Bridge is the second bridge road connecting Youngjong Island to the land following Youngjong Grand Bridge opened to the traffic in November 2000. It will serve as a transport route linking the Korea's economic strategy base for Economic-Hub in North East Asia, Incheon Songdo Free Economic Zone to Youngjong IC of the global high-tech international hub airport, Incheon International Airport. It is designed with approximately 12km-long highway bridge road across Incheon Harbor Navigational Route and Toll Plaza. The purposes and the expected effectiveness of this project are to serve as a catalyst for Korea's transition into the Economic-Hub in North East Asia, for the convenient traffic networks with the southern part of Seoul Metropolitan Area, and for the activation of foreign investments in Social Overhead Capital (SOC) in the future as the first-ever participation of a foreign investor as a Concessionaire in a private investment project.

The Client (the "Concessionaire") is Incheon Bridge Co., Ltd. which is a joint venture company of AMEC(51%- British company) and Incheon City(49%), and holds all responsibilities of the project financing. Incheon Bridge shall be handed over to Korean Government with BOT System after the operation by the Concessionaire for 30 years from the completion date of the project. The construction period is from June 2005 to October 2009 for a total of 52months, and the contract price is approximately one trillion and twenty billion won excluding the operating expenses.

The navigational route to be located in the center of the bridge is designed with a width of 625.5m and a height of 74.0m as a global scale suitable to the Incheon City's plan for global standard city. Fig.1.1 shows the location of Incheon Bridge Project's alignment. This project consists of the cable-stayed bridge with 800m main span and 5 continuous steel deck box girders located at the navigational route, the approach bridge with 145m span precast concrete box girders by Balanced Cantilever Method (BCM), and the viaduct with 50m span and 5 continuous precise concrete box girders by Full Span Launching Method (FSLM). The details of the bridge structure are as shown in Table 1.1.

The bridge with a total width of 33.4m carries a three-lane dual carriageway, and the design speed is 100km/h. The design and construction of this bridge project is carried out simultaneously by applying Fast-Track Method. AASHTO LRFD Specifications is applied as a design standard, and for live load, the domestic design standard (DB24) is additionally applied, beside the live load requirements (HL93) in AASHTO LRFD Specifications. The Incheon Bridge is designed to withstand a wind velocity of 72m/s and an earthquake with a magnitude of 7, and to secure the 100 year-durability. As of Oct. 2008, the whole sub-structure works including the CSB pylon is completed, and CSB steel deck plate and cable works and superstructure works of the viaduct and approach bridge are currently being carried out.

<Fig. 1.1> Incheon Bridge Project

<Table 1.1> Information of Incheon Bridge Project

Item	West		CSB			East		Total
	Viaduct	Approach Bridge	Side Span	Main Span	Side Span	Approach Bridge	Viaduct	
Span(m)	5,950	889	80+260	800	80+260	889	2,450	11,658*
Substructure & Pylon	ψ1.8, ψ2.4, ψ3.0 RCD Π shaped Pier	ψ2.4 RCD	ψ3.0 RCD	ψ3.0 RCD Inverted Y shaped concrete pylon	ψ3.0 RCD	ψ2.4 RCD	ψ1.8, ψ2.4, ψ3.0 RCD Π shaped Pier	
Superstructure	FSLM	BCM	Steel Deck Plate			BCM	FSLM	

* Excluding TP Area

1.2 Necessity of Durability Design

Generally, structures under the marine environment suffers the corrosion and the complex phenomena of physical and chemical action due to penetration of the seawater into the structure, therefore, their durability can be easily decreased as compared with other structures under normal environment. The marine environment includes some indirect effect caused by airborne seawater from many kilometers away and some direct effect caused by seawater on seashore or on the sea. Since Incheon Bridge is located on the marine area, it is directly affected by salt-attack. Thus, considering the salt-attack, Incheon Bridge Project Performance Requirements(PPR) requires to secure the target durability period as following.

For durability design of reinforced concrete structure against carbonization or chlorination damage shall be in accordance with ["(draft) guidelines for durability design/construction/maintenance & operation of reinforced concrete structure against carbonization or chlorination damage', Korea Concrete Institute (2002.11)]. The objective durability life span shall be durability level 1 (approx. 100 years). When paints or waterproofing layer is used, the cover depth specified above shall not be reduced considering the possibility of losing them.

Therefore, the durability of the concrete is carefully considered and analyzed from the early stage of the project and the concrete structure is constructed according to the durability design based on the said consideration and analysis. And, we are currently preparing the maintenance plan for long-term durability. In this paper, the durability design method/background, the quality control and the long-term durability review plan which are applied to the Incheon Bridge project shall be briefly explained.

2. Durability Design for Incheon Bridge Concrete Structure

2.1 Outline

2.1.1 Concept of Durability Design

In the concrete durability design, the critical deterioration factor is salt-attack. The salt accumulated inside of concrete by using sea-sand or penetration of sea-salt aerosol (seawater moisture) from the marine environment will accelerate the corrosion of reinforcing bar, therefore the performance of the concrete structure is decreased. The damage caused by salt-attack is generally classified according to the corrosion level of reinforcing bar inside of concrete, and also it can be divided into 2 types according to its causes, such as salt inside of the concrete and sea-salt aerosol from the sea. In case of damage caused by salt inside of concrete, the durability might be improved by controlling the total volume of chloride ions in concrete. And, for the chloride ions penetrated into concrete after completion of the work due to marine environment or deicing-material application, various action plans to improve the durability is required. Therefore, in order to study how to secure the durability against salt-attack, it is important to establish the durability design method against salt-attack considering the environmental conditions, penetration level of chloride ions, and limit of rebar corrosion.
The durability review for Incheon Bridge project is performed pursuant to the guidelines for durability from the Korea Concrete Institute, as prescribed in the PPR. The domestic specification is complied for detailed items such as testing data or analysis method, however, if there are no relevant requirements or data, similar testing data or overseas specification is applied. As for the measures against damage of salt-attack, the method proposed in the guidelines for corrosion proofing of marine concrete structure from Japan Concrete Institute was examined. There are 2 types (Type I & Type II) of measures for corrosion proofing. According to the said guidelines, the design shall be prepared on concentrating the Type I first in order to secure the sufficient durability period. If it is not possible to secure the durability period with the Type I corrosion proofing

measures, the Type II shall be adopted. In Type I method, the crack width shall be controlled by using high-strength or high-quality concrete and the sufficient concrete cover thickness shall be secured. In Type II method, (in case that it is not possible to secure the design life,) concrete surface treatment, corrosion proofing material, or cathodic protection system shall be applied or epoxy-resin coated rebar or salt-tolerant rebar shall be used. Many different kinds of protection measures against salt-attack were reviewed in consideration of site conditions. In Type II method, there are some weak points to be improved, and it is regulated in the PPR that when paints or waterproofing layer is used, the cover depth shall not be reduced considering the possibility of losing them. And, the cover thickness calculated according to Type I method would not affect the constructability. Therefore, in Incheon Bridge project, the durability period shall be secured by dense concrete and cover thickness control thru Type I method.
In order to secure the durability thru Type I method, the dense concrete shall be prepared. The density of concrete is made up by intrusion prevention of water, chloride ion and oxygen. The rebar corrosion appears only when the water exists, so when the permeability of concrete is excellent, the rebar is apt to corrode easily. The permeability of concrete is decreased when the water-cement ratio is low and the cover thickness is thick. And, the resistance against pressure by corrosion products is generally high at the dense concrete, so the density of concrete is important for corrosion proofing of concrete structure. In order to prepare dense concrete, generally the unit cement content is increased and water-cement ratio (W/C) is decreased. Increasing the concrete cover thickness is to control or delay the penetration of noxious substances such as i) oxygen, water, salt (salt-attack) ii) carbonic acid gas (neutralization) iii) water (frost damage). The concrete cover thickness is important against salt-attack as well as general durability.

2.1.2 Durability Life of Structure

A certain level of durability is secured for the concrete structure upon completion, however, it is decreased with time because of effects of the surrounding environmental load. When the actual durability life is lower than the design durability life, the failure in structure occurs. Thus, in order to prevent any failure in structure, the target durability life shall be established considering the social/economic importance of the structure upon the durability design. It would be very important first step to secure the durability of the structure during the service period. The durability life can be classified into 3 kinds, such as target durability life, design durability life and remaining durability life.
(1) Target Durability Life
It is the durability life of the structure or its component parts determined by the designer, operator or owner at the planning phase based on requirements such as purpose or function of the structure.
(2) Design Durability Life
It is durability life of the structure estimated/established on the design and planning phase considering the various conditions such as structure’s location, environment, critical section, construction management and maintenance. The design durability life could mean a structural concept, so it can be presented by the structure’s strength and durability.
(3) Remaining Durability Life
It means the remaining period until the durable failure occurs in the structure or its component parts. It can be predictable base on the current condition of the structure or its component parts. The remaining durability life shall be predicted based on various data such as current condition of concrete, critical environmental factors affected to concrete, and concrete performance degradation process/speed. And, the important factors to determine the remaining durability life are i) structure’s scale and importance, ii) structure’s type and function, iii) economical efficiency, iv) difficulty in maintenance.

Therefore, the target durability life of the Incheon Bridge project is ultimately established as 100 years with review results for the said factors, as regulated in the PPR, and durability design is executed on the said target durability life.

2.2 Applied Durability Design Method

2.2.1 Outline

For the durability design of the Incheon Bridge Project, Life-365 Service Life Prediction Model is selected among various methods, which is proposed by the America Concrete Institute (Service Life Committee). Life-365 programme was developed by the America Concrete Institute (ACI Committee 365) in 2001 in order to evaluate the durability life against the rebar corrosion caused by penetration of chloride ions. It is being used for many projects so far.

The input data required for the evaluation of durability life is surface chloride content, critical chloride content, and concrete diffusion coefficient, etc. For the surface chloride content, the data measured at Seohae Bridge (intertidal zone) and the data proposed in the concrete standard specifications (excluding intertidal zone) were applied, and the critical chloride content stated in the concrete standard specification is used. And, the diffusion coefficient was derived the chloride ion diffusion coefficient in abnormal status by the accelerated test (potential difference).

RCD Piles, Pier and Pylon are to be analyzed. RCD Piles are located in sea area or intertidal zone and its design strength is 30MPa. Piers are located at the atmosphere on the sea area above E.L 5.5, and its design strength is 35MPa. Pylon is located in the environs on the sea area above E.L 13, and its design strength is 45MPa.

2.2.2 Chloride Ion Diffusion Analysis

The mechanism of chloride ion diffusion by void water is generally the most dominant one among many other mechanisms explaining how the chloride ion is penetrated into concrete. Tutti model of Fick's second law simply presents the chloride penetration into concrete thru void water.

$$\frac{dC}{dt} = D \cdot \frac{d^2C}{dx^2} \qquad (2.1)$$

Where, C : chloride ion concentration per unit weight percentage of concrete

D : concrete chloride diffusion coefficient thru void water

x : depth from concrete surface

t : time

The above Tutti model is widely used to describe the behavior of the chloride ion diffusion of the concrete structure subjected to chloride attack, and thereafter many other models modified based on Tutti model are presented. In Life 365 programme, the corrosion initiation time is presented as the chloride critical corrosion concentration at the depth from concrete surface. The simplified approach method based on the Fick's diffusion theory was used. On the assumption that the diffusion is the main cause of chloride ion penetration, the rebar corrosion initiation time can be estimated by seeking the solution with the above (2.1) equation and the finite difference method. The concrete diffusion coefficient is decided by using "Norwegian standard method(NT BUILD 443)". In this method, i) the specimen shall be cured for 28 days at the laboratory, ii)other surfaces excluding the penetration section shall be treated for waterproofing, iii) this specimen shall be immersed, iv) the sample shall be collected for each depth, and v) the chloride ion concentration is measured.

In order to estimate the rebar corrosion initiation time, the following information is required.

- Ambient Temperature & Exposure Condition against Salt-Attack (according to the geographical location)
- Structure Type : 1 Dimension (Slab, Wall, Bottom Plate), 2 Dimensions (Pier, Pile, etc.) Model
- Concrete Cover Depth (Xd)
- Water-Binder Ratio(W/B), Type/Volume of Admixture/Corrosion-Proofing Agent
- Type of Steel Material, Coping, Membrane or Sealer

2.3 Condition of Chloride Diffusion Analysis

The concrete structure of the Incheon Bridge project is designed with the design strength of 30MPa, 35MPa and 45MPa. The Water to Binder Ratio (W/B) is determined based on the durability design standard, previous construction data and preliminary testing, 40% for 30MPa, 38% for 35MPa and 42% for 45MPa. As concrete materials for Type I Method, Tow Component System (Blast-Furnace Slag 50%) and Three Component System (Blast-Furnace Slag 35% + Fly Ash 15%) are selected, which has excellent resistance for salt-attack. The concrete design strength is determined considering the concrete structure design standard (more than 27MPa), durability (including the constructability against cover depth), and efficiency of member's section.
According to the data actually obtained in the west coast, the structure placed in intertidal zone is easier to be affected by salt-attack compared with the structure placed in splash zone. Therefore, it is regulated based on the PPR that the area from EL. -4.635m to EL. 4.635m is intertidal zone, and according to the concrete specifications Chapter 15 Article 2.2(2003) the area from EL. 4.636m to EL. 5.112m is regulated as splash zone. And, any structure placed in some of between intertidal zone and splash zone is considered that it is placed in the intertidal zone.
The chloride ion diffusion coefficient is determined thru the test, and the surface chloride content and the critical chloride content provided in the concrete standard specifications (2003, marine concrete section) are applied. The analysis conditions applied to the durability evaluation are as shown in Table 2.1. For the surface chloride content in Table 2.1, the variation of surface chloride content of the concrete structure exposed to the marine environment stated in 『Chapter 15, Marine Concrete - 1.2 Generals』 of the concrete standard specifications(2003) is expressed as an invariable number. As shown in Table 2.2, each different invariable number is applied considering the distance from the sea-water level and shoreline, as the surface chloride content of the concrete structure exposed to the marine environment. And, it is recommended that it shall be 1.3 times considering the safety factor. It is assumption that if the distance from the shoreline is 25m, the distance from the sea-water level is 1m.

<Table 2.1> Analysis Conditions

Structure Type	Structure Location	Concrete		Diffusion Coefficient (m2/sec)	Surface Chloride Content (kg/m3)	Critical Chloride Content (kg/m3)
		Design Strength	Admixture			
Pile(CSB, Approach Bridge, Viaduct)	Underwater	30MPa (W/B 40%)	BFS 50%	7.53E-12	23.0	2.4
	Intertidal Zone				20.0	1.2
Pier	Intertidal Zone	35MPa (W/B 38%)	BFS 50%	6.73E-12	20.0	1.2
	EL. 5.5				6.3	1.2
	EL. 7.0				4.7	1.2

CSB Pylon	EL. 13.0	45MPa (W/B 32%)	BFS 50%	3.93E-12	3.3	1.2
Viaduct Girder	EL. 10.0		BFS 50%	3.93E-12	3.9	1.2
			FA15%+BFS35%	2.97E-12	3.9	1.2
Approach Bridge Girder	EL. 34.0		BFS 50%	3.93E-12	2.1	1.2
			FA15%+BFS35%	2.97E-12	2.1	1.2

<Table 2.2> Concrete Surface Chloride Content (Structure exposed to the Marine Environment) (kg/m³)

Splash Zone	Distance from Coastline (km)				
	Coastline neighborhood	0.1	0.25	0.5	1.0
13.0	9.0	4.5	3.0	2.0	1.5

※ Underwater : 23 kg/m³ , Intertidal Zone : 20 kg/m³ (Actual Measurement Data)

There is the diffusion coefficient for the age 28 days presented in the programme, however, in order to consider the material properties, the actual testing results was applied to the analysis. The diffusion coefficient applied to the test is the chloride ion diffusion coefficient of the abnormal state obtained the accelerated test, determined by the chloride ion diffusion model proposed by Tang. The decay rate of diffusion coefficient was calculated by using the diffusion coefficient measured up to the age 9 months, and its results are presented in Table 2.3.
According to the exposure testing data, the critical chloride content is evaluated within 1.2～2.4 kg/m³. It is known if the structure is always under the seawater, the oxygen penetrated into the concrete becomes subdued so the corrosion rate is retarded. Considering this, the critical chloride content could be increased up to 2.4 kg/m³ according to the relevant circumstance. Therefore, for the structure located in the splash zone, 1.2 kg/m³ stated in the concrete standard specification is applied as the critical chloride content, and 2.4 kg/m³ is applied for the structure located under the sea-water as shown in Table 2.1,

<Table 2.3> Chloride Ion Diffusion Coefficient

W/B (%)	Admixture	Diffusion Coefficient (*E-12 m^2/sec)			
		28days	91days	180days	270days
47	BFS 50%	11.1	7.2	6.5	4.3
	FA15%+BFS50%	8.8	5.4	3.1	2.7
42	BFS 50%	8.6	5.3	4.7	3.2
	FA15%+BFS50%	6.5	4.0	3.6	2.9
37	BFS 50%	6.3	3.7	2.5	2.4
	FA15%+BFS50%	5.0	3.8	4.5	4.3

2.4 Chloride Ion Diffusion Analysis Result

Table 2.4 & 2.5 shows the estimated durability life for each structure section considering the required concrete cover depth, which are obtained from the chloride ion diffusion analysis. Particularly, Table 2.4 presents the analysis results for the design strength of 30MPa, showing the durability life of the steel casing calculated with 0.4mm/year (standard 0.3mm/year + safety factor 30%), and the concrete durability life among the structure's target durability life (100 years).There are two types of concrete used for RCD piles, underwater concrete for the above section of pile tip and antiwashout underwater concrete for the pile tip section. The socket section means that there is no steel casing, and the casing section is located above the socket section. Since most of

socket and casing section are placed under the seawater, however, some of casing section is in intertidal zone so the environment condition are classified with the underwater and intertidal zone. According to the analysis results, more than 007mm of cover depth is required for the structure located under the seawater to secure the 100 year of the durability life, and for the structure located in the intertidal zone, more than 115mm of cover depth shall be secured.

Table 2.5 shows the analysis results for the structure with the design strength of 35MPa, 45MPa located in the intertidal zone and the atmosphere on the sea area. In case of the structure with the design strength of 35MPa, Two Component System Mix Design with 50% Blast-Furnace Slag was reviewed since it would be produced at the marine batching plant. And, for the structure with the design strength of 45MPa, Three Component System Mix Design with 35% Blast-Furnace Slag and 15% Fly Ash was additionally reviewed. According to the review results, the cover depth satisfying the 100 year durability under every possible environment conditions is presented.

<Table 2.4> Analysis Result : Design Strength 30 ㎫

Structure Type			Environment Condition	Concrete Type	Concrete Cover Depth (mm)	Casing Durability Life (Casing Thickness)	Structure Durability Life (Concrete Durability Life)
CSB Pile	Pylon (Diameter 3.0m)	Socket	Underwater	30MPa (W/B 40%)	107	0 year	105
		Casing	Interdidal Zone		115	55 years (22mm)	156 (101)
	Anchor Pier (Diameter 3.0m)	Socket	Underwater		107	0 year	105
		Casing	Interdidal Zone		115	55 years (22mm)	156 (101)
Approach Bridge Pile	(Diameter 2.4m)	Socket	Underwater		107	0 year	105
		Casing	Interdidal Zone		115	45 years (18mm)	146 (101)
Viaduct Pile	Pile Cap Type (Diameter 1.8m)	Socket	Underwater		107	0 year	105
		Casing	Interdidal Zone		115	35 years (14mm)	136 (101)
	Pile Bent Type (Diameter 2.4m)	Socket	Underwater		107	0 year	105
		Casing	Interdidal Zone		115	45 years (18mm)	146 (101)
	Pile Bent Type (Diameter 3.0m)	Socket	Underwater		107	0 year	105
		Casing	Interdidal Zone		115	55 years (22mm)	156 (101)

<Table 2.5> Analysis Result : Design Strength 35, 45 ㎫

Structure Type	Environment Condition	Concrete Type		Cover Depth(mm)	Structure Durability Life(Year)
		Design Strength	Admixture		
(All) Pile Cap	Interdidal Zone	35 MPa (W/B 38%)	BFS 50%	115	101
Pier	EL. 5.5			79	100
Viaduct Pier Cap	EL. 7.0			68	100

CSB Pylon	EL. 13.0	45 MPa (W/B 32%)	BFS 50%	44	100
Viaduct Girder	EL. 10.0		BFS 50%	46	100
			FA15% + BFS35%	45	100
Approach Bridge Girder	EL. 34.0		BFS 50%	29	100
			FA15% + BFS35%	28	100

2.5 Applied Cover Depth

Comparing the results of the chloride ion diffusion analysis and the requirement stated in ASSHTO LRFD and the PPR, the cover depth to be used for the project is determined as following.

<Table 2.6>Analysis Results & Cover Depth

Structure Type			Concrete Type		Cover Depth (mm)			
			Design Strength	Admixture	Analysis Results	AASHTO* (PPR)		Cover Depth
CSB Pile	Pylon (Diameter 3.0m)	Socket	30 Mpa (W/B 40%)	BFS 50%	107	80		108
		Casing			115	80		115
	Anchor Pier (Diameter 3.0m)	Socket			107	80		108
		Casing			115	80		115
Approach Bridge Pile	(Diameter 2.4m)	Socket			107	80		108
		Casing			115	80		115
Viaduct Pile	Pile Cap Type (Diameter1.8m)	Socket			107	80		109
		Casing			115	80		130
	Pile Bent Type (Diameter 2.4m)	Socket			107	80		109
		Casing			115	80		130
	Pile Bent Type (Diameter 3.0m)	Socket			107	80		109
		Casing			115	80		130
(All) Pile Cap		Intertidal Zone	35 Mpa (W/B 38%)	BFS 50%	115	80		117
Pier		EL. 5.5			79	60		90
Viaduct Pier Cap		EL. 7.0			68	60		75
CSB Pylon		EL. 13.0	45 Mpa (W/B 32%)	BFS 50%	44	40		68
Viaduct Girder		EL. 10.0		BFS 50%	46	40	-	50
				FA15% +BFS35%	45	40	-	50
Approach Bridge Girder		EL. 34.0		BFS 50%	29	40	-	45

			FA15% +BFS35%	28	40	-	45

* In case of AASHTO LRFD(PPR), the coefficient of 0.8 can be applied if the Water/Cement Ratio is lower than 40%, and the distance means from the center of the main rebar to the surface. For others, the distance means from the outermost rebar to the surface.

2.6 Quality Management during Construction

The outcome from the durability design was reflected to the concrete mix design and cover depth of the structure. In case of concrete, the mix design for each required strength is completed before the construction, and the chloride ion diffusion coefficient was checked. And, if there was any change in the mix design due to the change of the aggregate supplier or admixture, the durability test was operated to confirm whether there is change in durability performance. And also, in order to confirm the quality, the specimen for every 1,000m^3 ready-mix concrete was manufactured for the test of durability performance. As of October 2008, all the testing results are fully satisfied with the quality requirement in the design, it is believed that there is no particular issues or problems on the durability of the structure.

3. Long-Term Durability Monitoring Plan

3.1 Outline

The salt-attack to concrete has been continuously studying within Korea, however, there is a limit to applying the overseas specification requirements to the domestic project since there is difference of environmental conditions, concrete quality, etc. And also, the concrete durability study and its test results are limited so it is not easy to estimate accurate expectation how much the concrete durability would be decreased as compared with the target durability life. Therefore, if the long-term durability monitoring is carried out for the structure to evaluate the durability performance of the concrete structure, it would be good for maintenance. In case of the Incheon Bridge project, there was a comment instructing the monitoring for long-term concrete durability upon the design deliberation in the early stage, so the testing plan was established. In the test, the specimen shall be exposed to the outside environmental conditions at the same location of the structure, so the chloride diffusion rate shall be defined and the basic information to examine and analyze the condition of salt-attack environment shall be provided. The results from the long-term measurement after completion shall be used for verifying the already-performed durability design, estimating the further durability design and concrete durable period. It would be also used as data required for maintenance and management.
In this chapter, the long-term monitoring plan prepared for the Inchen Bridge project and the measurement results obtained from some measurement devices installed according to the said plan are to be presented. The long-term durability assessment against the salt-attack to concrete would be performed by 3 types of measurement/evaluation, i) sea-salt aerosol measurement, ii) rebar integrity evaluation thru corrosion sensor, and iii) chloride penetration by natural exposure to the sea environment condition.

3.2 Sea-Salt Aerosol Measurement Test

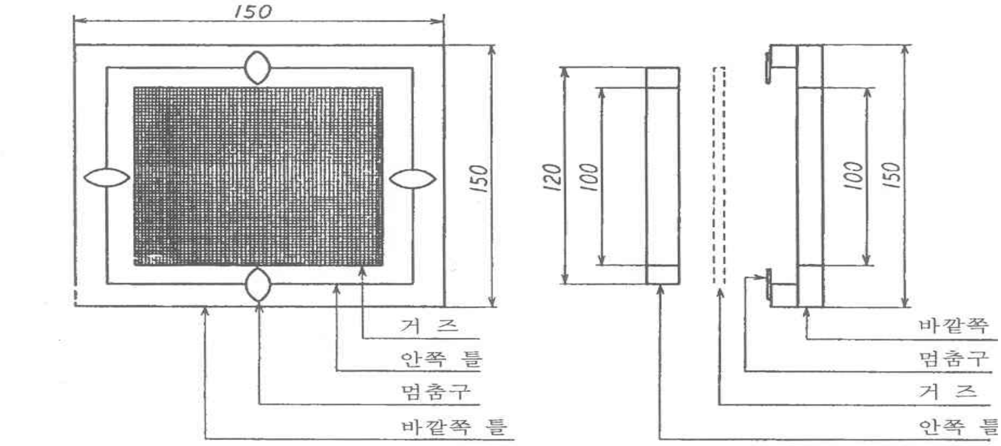
3.2.1 Test Outline

In case of salt-attack caused by the environmental condition, the sea-salt aerosol from bubbles and sea wave sticks to the concrete surface and it penetrates into the inside of concrete because of difference of salt concentration between inside and outside of concrete structure. Therefore, measuring the sea-salt aerosol is very important to provide basic information for examining the salt penetration level in the structure located on the sea area. Therefore, in order to consider the effect of sea-salt attack to the Incheon Bridge, the sea-salt

aerosol collecting device shall be installed at the same section with the exposure test, and the sea-salt content shall be measured and analyzed.

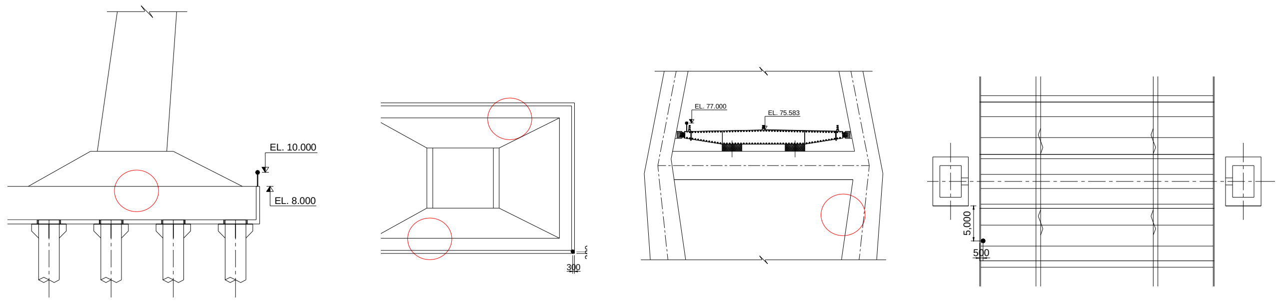
3.2.2 Test Details & Method

Generally, according to JIS Z 2382 (Determination of pollution for evaluation of corrosivity of atmospheres) and KS D 0060 (Recommended Practice for outdoor-exposure test), the sea-salt aerosol collecting device with 100mm×100mm sized medical gauze shall be prepared to collect the sea-salt aerosol from the air. Its size and shape are presented in Fig.3.1.



<Fig. 3.1> Sea-Salt Aerosol Collecting Device : Size & Shape

As shown in Fig. 3.2, the sea-salt aerosol collecting devices are installed at the top side of E1 pile cap and the upper side of the pylon girder in NW direction. Fig. 3.3 shows the sea-salt aerosol collection device actually installed on the site on 4th September 2008. The measurement shall be executed for 1 year, and at every 1 month, the gauze shall be changed with new one. The quantitative analysis for the gauze samples shall be carried out according to the JIS and KS requirement.



(a) Top Side of Pile Cap **(b) Upper side of Pylon Girder**

<Fig. 3.2> Location of Sea-Salt Aerosol Collecting Device

(a) Top Side of Pile Cap **(b) Upper side of Pylon Girder**

<Fig. 3.3> Sea-Salt Aerosol Collecting Device

3.3 Rebar Corrosion Measurement Test

In order to evaluate the steel corrosion after completion, the sensor shall be embedded in the inside/outside of Incheon Bridge Pylon (E1) to measure the corrosion loss by checking electric potential, electric current, electric resistance and temperature periodically, therefore the corrosion rate can be estimated. By using this system, the bridge operator can take necessary actions to prevent corrosion before corrosion loss occurs. This system is to monitor whether more than certain level of chloride content is penetrated into the concrete structure from the surface by using Anode-Ladder sensor which is installed during the construction. Anode-Ladder-System consists of 6 ea of black anode bars with 50mm interval as shown in Fig.3.4(a), and epoxy filler protects wire and PT1000 integrated temperature sensor. Sensors shall be installed not to affect the concrete cover, chloride penetration, and neutralization process. Fig.3.4(b) shows the installation of the sensor on the site.

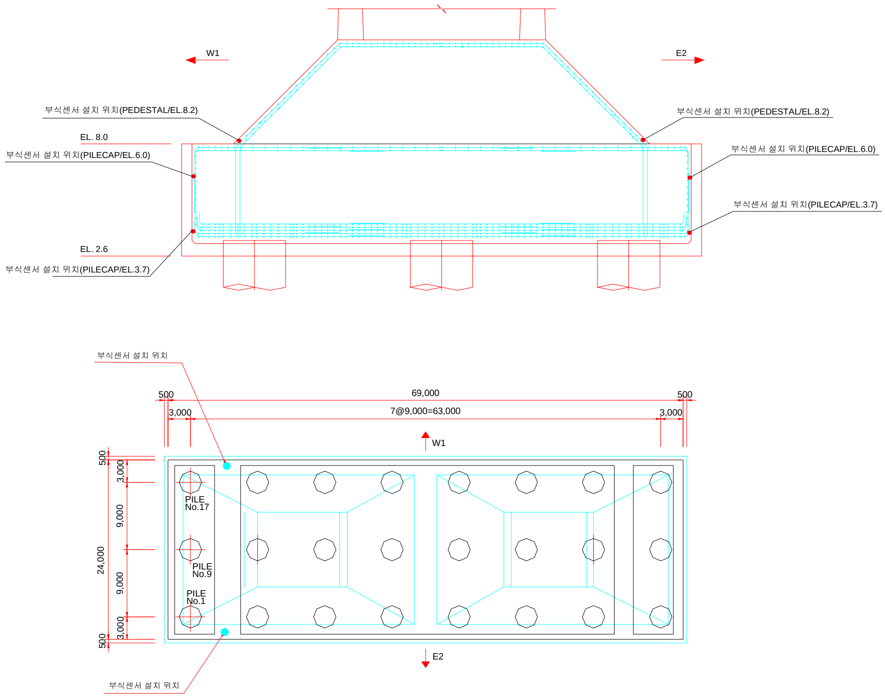
For 35MPa mix design, total 4 ea of sensors are installed, i) 2ea – E1 pile cap lower side surface EL.3.7, ii) 2ea – E1 pile cap side surfaces facing W1/E1 EL.6.0 And, for 45MPa mix design, 2 ea of sensors are installed at EL.8.2. Further information for sensors installation presented in Fig.3.5. And, its quantity and installation date are in Table 3.1. The distance of each single anode embedded in the concrete is 10mm(A1) to 100mm(A6) from the concrete surface. And, the reason why there is the interval distance of 50mm for each single anode is to prevent interaction between anode bars. All single anode system are embedded at the same depth of concrete with base level(rebar location).

(a) Corrosion Sensor **(b) Installation on the Site**

<Fig. 3.4> Corrosion Sensor & Installation

<Table 3.1> Corrosion Sensor : Quantity & Installation Date

Location	EL	Quantity(EA)	Date (Concrete Pouring Date)
Inside of Structure	+3.7	2	2006.4.17
	+6.0	2	2006.4.26
	+8.2	2	2006.5.27
Total		6	

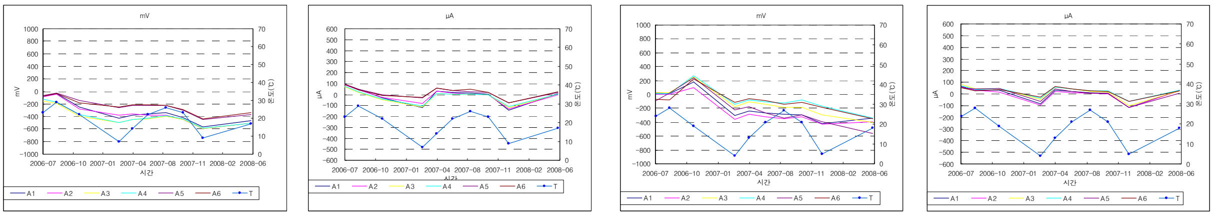


<Fig. 3.5> Corrosion Sensor Location

Before the completion, the measurement shall be performed 4 times a year considering four distinct seasons, however, it could be adjusted. And after the completion, only 1 time of measurement shall be operated, however, additional measurement can be arranged if necessary. As of 30 September 2008, total of 10 times of measurement has been carried out for the rebar corrosion monitoring. The measurement results presented in Fig.3.6 ~ Fig.3.8. In the data of the measurement result, several measurement values (East Section, 1st Measurement Level, Dec.2007) are not within the standard level of voltages stated in Chapter 3 Evaluation

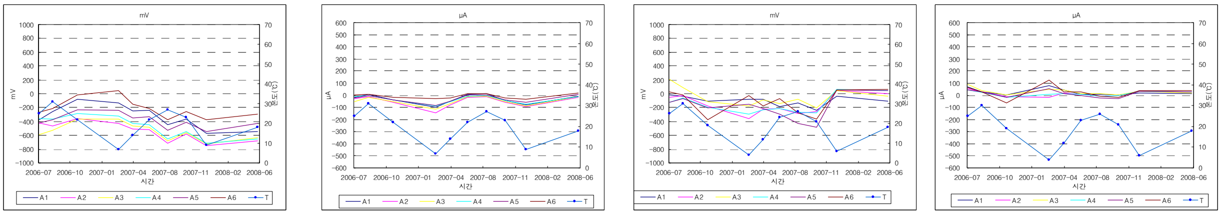
Method, however, they are the values expressed in comparison with the cathode bar and the voltage of cathode bar adjacent to the sea water level is also low. Therefore, it is concluded that no corrosion occurs. Sensor can be placed under the sea water level at the East 1st /2nd Level and West 1st Level, but others are placed above the sea water level so the voltage is pretty stable.

Generally, the corrosion of the rebar in concrete is affected by various factors of material(type of concrete, w/c, pH, etc.) / environment (temperature, humidity). In this project, voltage and current data from 10 times of measurement for approximately 2 years are collected, however, they are not enough to provide a certain current and voltage data implying the rebar corrosion. And also, the environment/measurement errors of the structure shall be considered. For example, even though the measurement data from East 1st Level (Dec. 2007) implies the rebar corrosion, it can not be concluded that the corrosion occurs if the later voltage data tends to increased. In order for clear judgment for rebar corrosion initiation, much more data shall be accumulated.



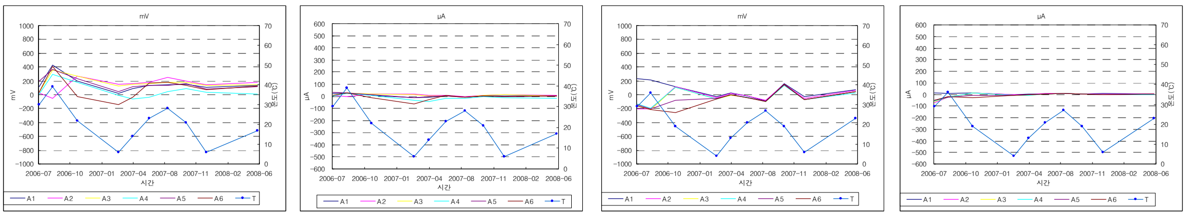
(a) East Voltage (b) East Current (c) West Voltage (d) West Current

<Fig. 3.6> 1st Level Measurement Results (E.L. +3.7)



(a) East Voltage (b) East Current (c) West Voltage (d) West Current

<Fig. 3.7> 2nd Level Measurement Results (E.L. +6.0)



(a) East Voltage (b) East Current (c) West Voltage (d) West Current

<Fig. 3.8> 3rd Level Measurement Results (E.L. +8.2)

3.4 Long-Term Exposure Testing

The salt content sticking to the concrete surface by environmental conditions penetrates into the inside of the concrete by diffusion caused by concentration gradient of chloride ion. Therefore, in this test, the specimen prepared by same mix design with Incheon Bridge East Pylon (E1) shall be exposed, and the depth of the salt content and its penetrated volume shall be checked in length of time. And, based on this, the concrete deterioration level and the chloride ion diffusion coefficient shall be estimated so that the concrete damage caused by salt-attack in the nature exposure could be verified. The concrete design strength, the environmental conditions of the specimen (exposure level), etc. are the test variables as shown in Table 2.3.2.

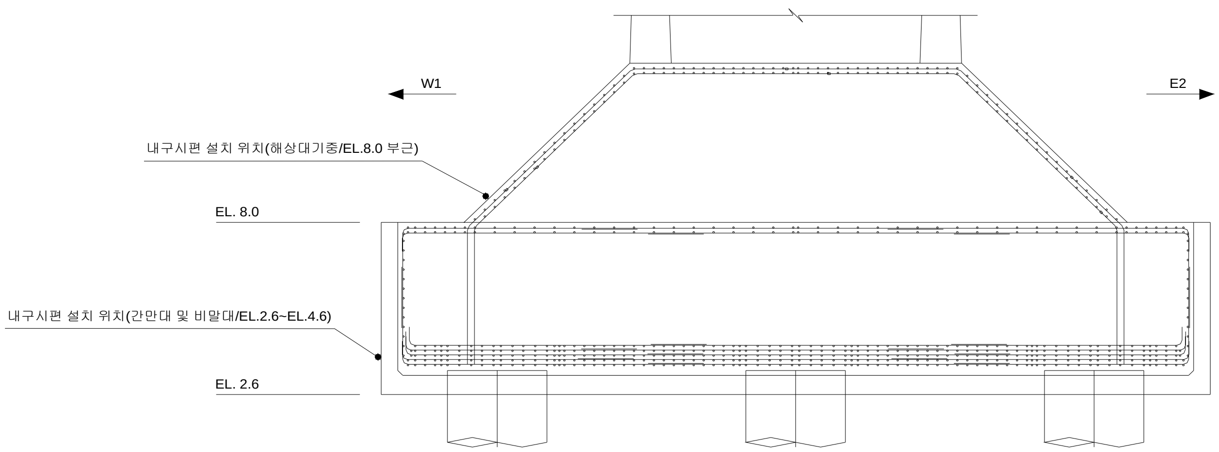
<Table 3.2> Test Variables

Division		Description
Concrete Design Strength	35 ㎫ (W/B 38%)	Pier, Foundation
	45 ㎫ (W/B 32%)	Pylon, Girder
Exposure Level	Atmosphere in Sea Area	Area affected by sea-salt aerosol
	Splash Zone / Intertidal Zone	Area affected by waves, high water ordinary mean tide + wave height Area under Wet-Dry Cyclic Conditions (due to tidal)

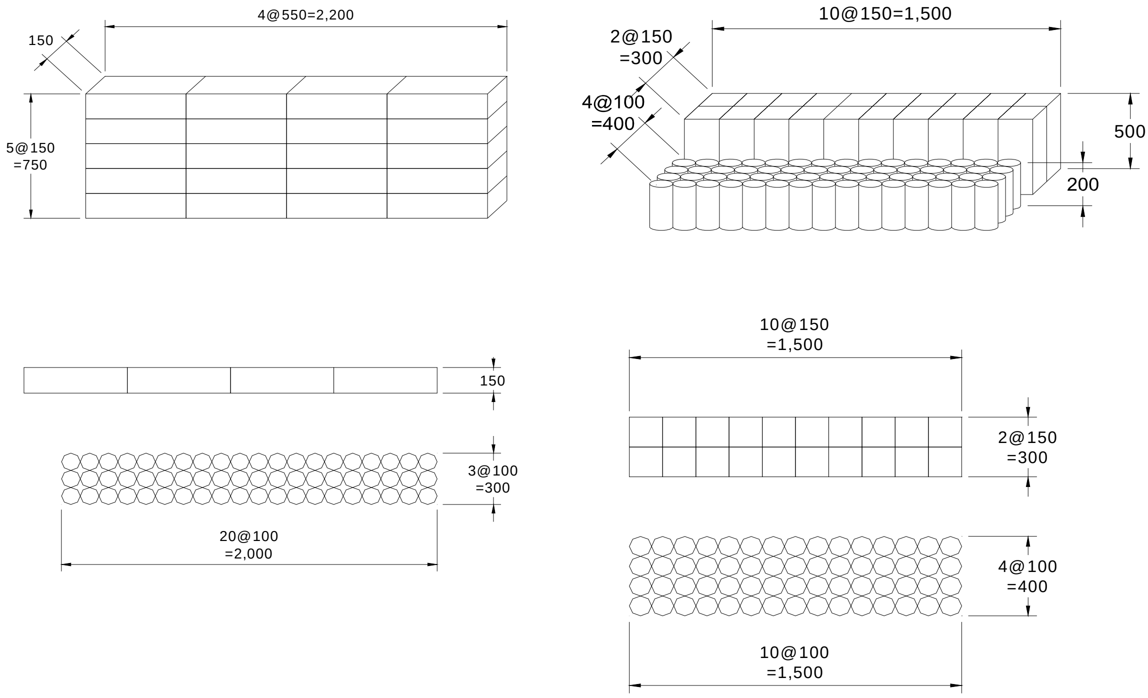
※ W/B : Water to Binder Ratio

※ Measurement of Sea-salt aerosol Content : The salt content is constant under the sea, however, the sea-salt aerosol content is different according to the outside environmental conditions. Therefore, the sea-salt aerosol content shall be measured. .

The location of the exposure test specimen is as shown in Fig. 3.9. These locations are selected to make same exposure environment with the structure, as intertidal zone, splash zone and atmosphere in sea area. The sea-salt aerosol is subject to ship wave, seasonal wind and sea wind. Therefore, the exposure test specimen shall be installed on the Pylon E1 (navigational route side) which is easily affected by impact of ship wave, seasonal wind and sea wind. Two kinds of specimen (Bar Type150mm×150mm×550mm & Cylinder Type ψ100mm×200mm) shall be prepared and arranged as shown in Fig 3.10. For the installed specimen, approximately 100 year long-term survey/observation shall be effected. The specimen shall be collected in 1 year, 3 years, 5 years, 10 years and afterward every 10 years, and the penetration depth of the chloride and its amount will be analyzed.



<Fig. 3.9> Locations of Specimens



(a) Installation in Atmosphere in Sea Area **(b) Installation in Intertidal Zone**

<Fig. 3.10> Specimen Arrangement Method

The procedures of the test are as following.

① Specimen shall be prepared by same mix design with the site, and water curing shall be conducted for 5 days.

② After completion of water curing, other surfaces excluding the penetration surface shall be coated by epoxy.

③ The test shall be carried out in 1 month, 6 months, 1 year, 3 years, 5 years, 10 years and afterward every 10 years (total 15 times) after specimen is exposed for long-term period as shown Fig.2.3. The compressive strength, chloride penetration depth, chloride penetration content shall be checked.

④ The diffusion coefficient shall be calculated with the chloride penetration content.

The test shall be executed by SCJV before the completion and by the Incheon Bridge Maintenance Office after the completion. The test is to examine the variation of chloride by measuring the chloride penetration depth and the chloride penetration content for ages of the test specimen.

4. Summary & Conclusion

Considering the importance and economical efficiency of the structure, the target durability life is established as 100 year, and the durability design is performed accordingly. In order to secure the durability, Type I corrosion proofing method is applied. The mix design is derived with proper water-cement ratio and materials decided based on the test results. The durability performance of the determined mix design is evaluated by using Life-365 programme from the ACI, and for conditions required for the evaluation, data stated in the Korea Concrete Specification, testing results and measured values are applied. The said evaluation revealed that the target durability life (100 year) is fully secured at all parts of the structure, and even during the construction period, continuous quality control is performed to check any change on the durability performance.

The long-term monitoring plan is established to check the results of the durability design and to evaluate the long-term durability performance. Accordingly the sea-salt aerosol content is measured, and the rebar corrosion sensor / the exposure test specimen for long-term exposure test are installed. If the concrete durability performance is checked thru continuous survey or observation after completion, the Incheon Bridge could be the safest bridge in Korea in consideration to the securing of the 100 year of the target durability life.

5. Reference

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